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HIGHWAY RESEARCH REPORT

THE SAN FERNANDO EARTHQUAKE

SOILS AND GEOLOGIC INVESTIGATIONS IN RELATION TO HIGHWAY DAMAGE

71-10

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632119

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

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DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

RONALD REAGAN, *Governor*

September 1971
Interim Report
M&R No. 632119
D 0543

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is an interim research report titled:

THE SAN FERNANDO EARTHQUAKE

SOILS AND GEOLOGIC INVESTIGATIONS
IN RELATION TO HIGHWAY DAMAGE

BY

R. H. PRYSOCK AND JOSEPH P. EGAN, JR.

Supervised by D. L. Durr and Directed by Travis Smith

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Prysock, R. H. and Egan, Joseph P., Jr., "The San Fernando Earthquake-Soils and Geologic Investigations in Relation to Highway Damage", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Interim Report No. M&R 632119, September 1971.

ABSTRACT: The findings to date of an investigation of the effects of the San Fernando earthquake on freeway earthworks are presented. Regional geologic and tectonic history are reviewed. Effects of the earthquake on cut slopes, embankments, embankment foundations and natural ground are discussed and shown on a map. The interactions between earth structures and bridges, pavements and drainage facilities are described. The siesmic risk of the San Fernando Valley is discussed.

KEY WORDS: bridge approaches, earthquake effects embankments, fault location, geological faults, landslides, magnitude, pavement damage, slope stability, surface cracks, surveys, data collection.

ACKNOWLEDGEMENTS

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Marvin McCauley prepared the Discussion of Seismic Risk of the San Fernando Valley, and John Campbell assisted in preparing the Introduction.

This work was done in cooperation with the U.S. Department of Transportation, Federal Highway Administration. The findings and opinions expressed in this report are those of the authors and not necessarily those of the Federal Highway Administration.

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INTRODUCTION

THE SAN FERNANDO EARTHQUAKE

Magnitude

The San Fernando earthquake of February 9, 1971, was the most damaging quake to occur in California since the Long Beach earthquake of March 10, 1933. It was felt north to Fresno, east to Las Vegas, and south to Mexico. The initial shock was registered by Cal Tech seismologists at 42 seconds after 6:00 a.m. with a magnitude of 6.6 (Richter) followed at 6:01 by a second shock of 5.1, then four other after shocks close together. This series lasted about five minutes. A total of 199 after shocks, 3.0 or greater, had been recorded through February 23.

Location

The epicenter of the quake was located by Cal Tech seismologists over the Soledad Canyon Fault (a minor rift some three miles in length) at its junction with the larger San Gabriel Fault. They further described the earthquake as taking place in the maze of faults that characterize the geologically unstable base of the San Gabriel Mountains. Geographically, this area is some 25-30 miles northwest of the Los Angeles Civic Center, or seven miles east of Newhall, as shown in Figure 1. With reference to damaged roads, the epicenter is located about eight miles northeast of the Route 5/210 Interchange and about two miles south of Route 14 near Soledad Canyon. Focal depth has been determined to be about seven miles.

The earthquake occurred in an area which has had relatively low seismicity. Only one strong, destructive earthquake is known to have occurred previously in the San Fernando-Newhall area. This took place in 1893 about eight miles southwest of Newhall, registering about VIII-IX on the Modified Mercalli Scale.

C. R. Allen of Cal Tech has reported that nothing in the recent seismic history of the Northern San Fernando Valley would indicate the area to be a more likely candidate than any other area for a 6.6 magnitude earthquake. Allen further points out, however, that the San Fernando earthquake was no great surprise since a quake of at least this magnitude occurs in Southern California on the average of about once every four years.

Tectonic Movement

Regional tectonic movement consisted of an upper plate (Figure 2a), more or less delineated by the inverted "U" shape formed by the aftershock locations shown in Figure 1, that moved to the south and west along a thrust fault plane dipping about 45° to the north. This upper plate moved over the lower plate as rupture progressed along the thrust plane from the hypocenter to intercept ground surface in the Sylmar-San Fernando area. Because of the shallow fault depths and large ground displacements, this was the area in which damage to engineering works was concentrated.

Continuing studies of the aftershocks by Cal Tech seismologists are contributing to the overall picture of tectonic movement. These shocks, with an average focal depth of about four miles (maximum eight miles), have been divided into the eastern group, the epicentral group, and the Chatsworth group (Figure 1). According to Hanks, et al, (3) the focal depths of the eastern group are fairly shallow and are above the thrust plane as defined by the epicentral group (Figure 2b). Depths of the Chatsworth group, on the other hand, are deeper than the thrust plane. Based partly on this information Whitcomb (7) has suggested a model to describe the overall movement.

According to Whitcomb's model, the upper plate is breaking up in a complex pattern in the zone of the eastern group of aftershocks; movement of the upper plate became arrested along its northwestern boundary (Chatsworth group of aftershocks) by the adjacent crustal materials; the lower block is thrusting under the upper plate along a near vertical fault striking to the northeast along the axis of the Chatsworth group of aftershocks.

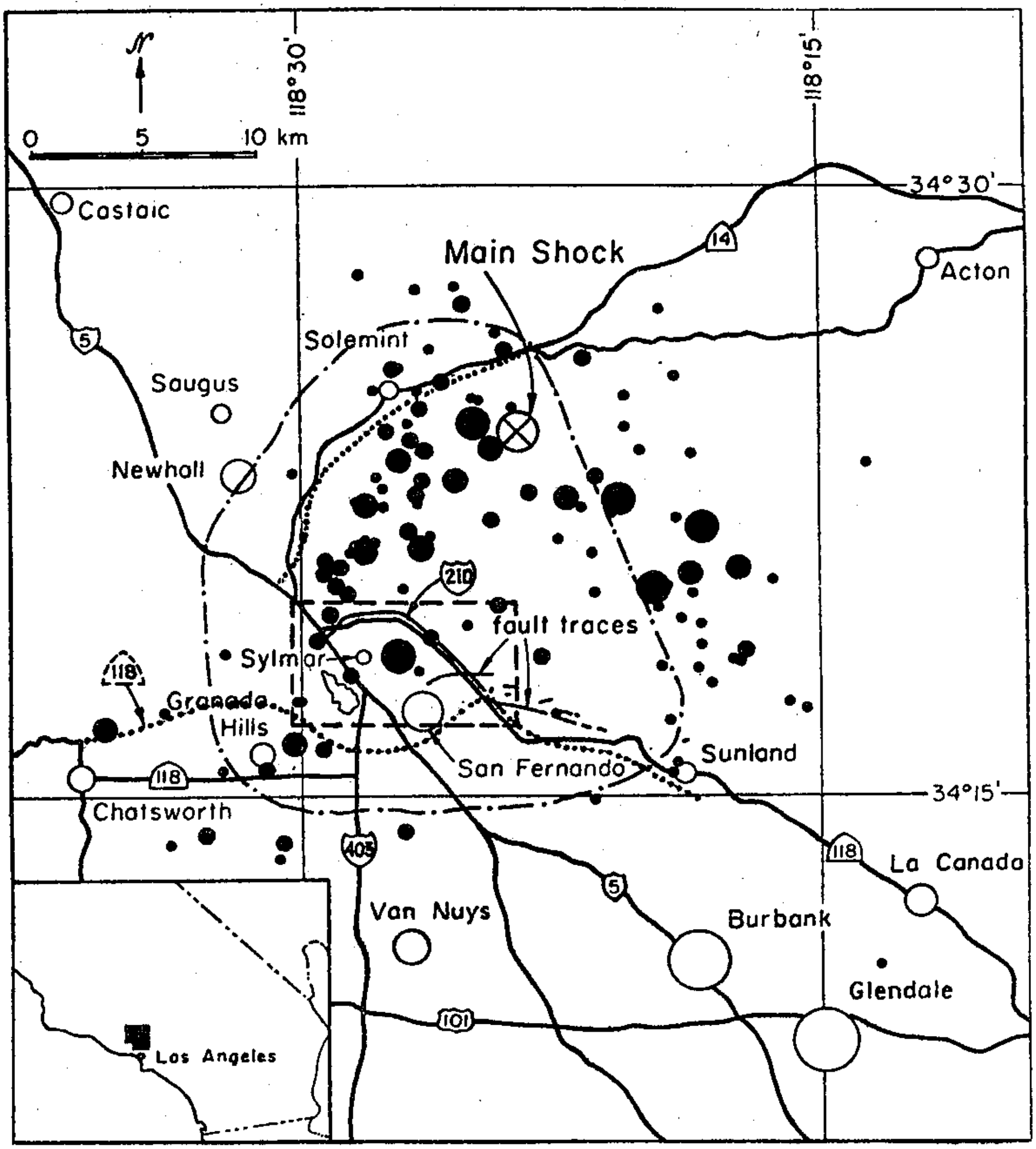
Ground Accelerations - Measured and Estimated

Although the San Fernando earthquake's magnitude was only moderate, the severity of ground motion was the maximum recorded during any earthquake - up to 75% of the earth's natural gravitational acceleration (0.75 g) at Pacoima Dam according to the findings of a 12 man panel, headed by Dr. Clarence R. Allen of Cal Tech.

Los Angeles County Engineer John A. Lambie (8) stated that "the tremendous energy release in the locality (of Olive View Hospital) caused horizontal and vertical ground shaking exceeding the 6.5 earthquake." He further stated that "ground shaking equaled or exceeded an 8.0 earthquake at the point of maximum intensity." George Housner, director of Cal Tech's earthquake engineering research, believes the acceleration force of the temblor at Olive View Hospital was 30 to 50% of the force of gravity. This would be the highest ever recorded throughout the world. (8)

Readings at Century City in western Los Angeles were 0.17 g and in downtown Los Angeles, a force of 0.13 g was measured.

The accelerometer at Pacoima Dam, located about five miles south of the epicenter and about 3.5 miles east of Olive View Hospital, showed a maximum horizontal acceleration somewhat greater than that of gravity. It had been previously estimated



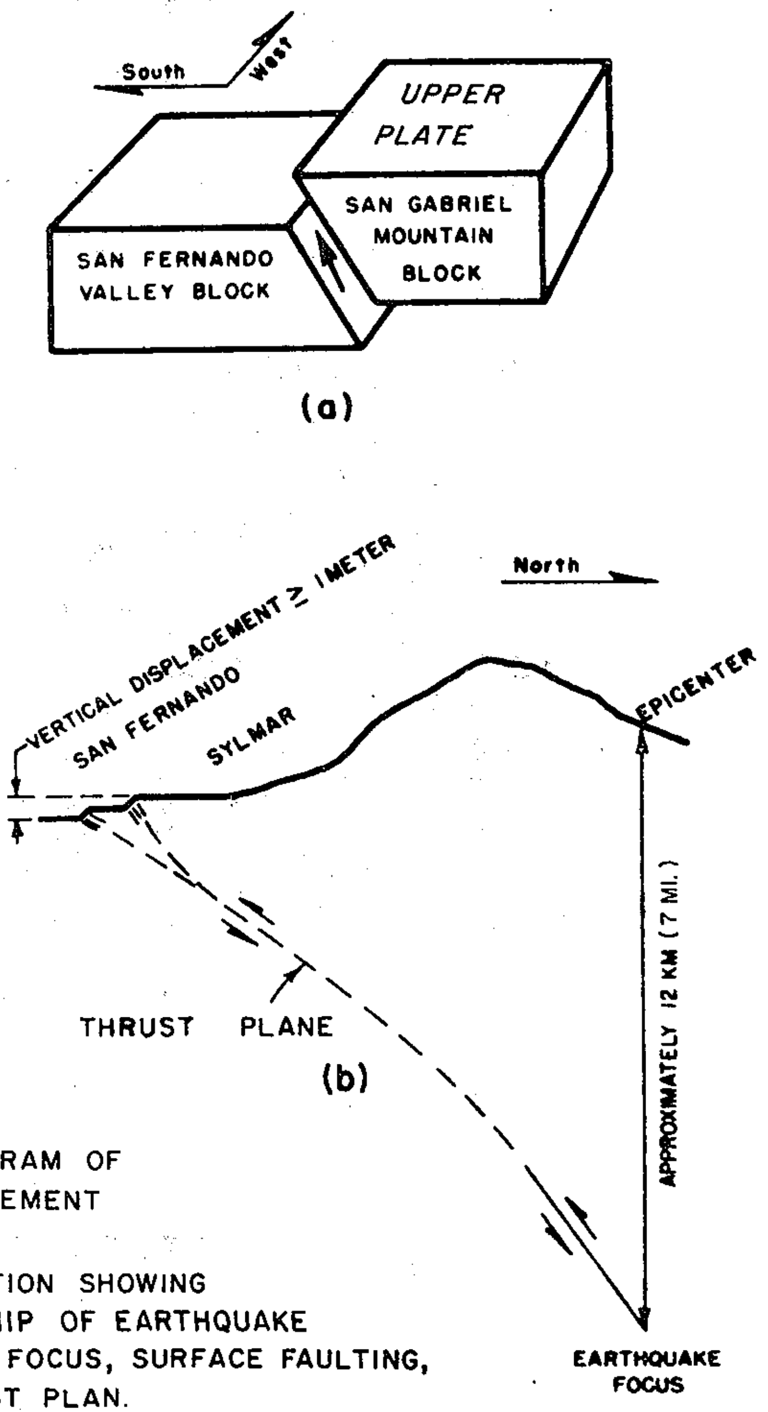
MAP AFTER ALLEN ET. AL. (REF. 1)

—·—·—	AREA OF FIELD STUDY
— — —	MAPPED AREA
·········	ADOPTED OR UNDER CONSTRUCTION

AFTER SHOCKS

•	3.0 - 3.4
●	3.5 - 3.9
●	4.0 - 4.4
●	4.5 - 5.1

Figure 1 GENERAL AREA OF FIELD STUDY, MAPPED AREA, AND AFTERSHOCKS



(a) BLOCK DIAGRAM OF FAULT MOVEMENT

(b) CROSS-SECTION SHOWING RELATIONSHIP OF EARTHQUAKE EPICENTER, FOCUS, SURFACE FAULTING, AND THRUST PLAN.

Figure 2 BLOCK DIAGRAM AND CROSS SECTION OF FAULTING

AFTER R. GREENFELDER, (REF. 2)

that a magnitude 6.5 shock should produce an acceleration of 0.1g on "better ground", whereas a maximum of 0.3g has been predicted for deep alluvium. The ground motions experienced during the San Fernando earthquake were therefore much more severe than would have been expected for a shock of its magnitude.

RESUME OF DAMAGE

State Highways

The heaviest concentration of road damage occurred at the Route 5/210 Interchange and along the completed five-mile portion of Interstate Route 210. Portions of Interstate Routes 5 and 405 and State Routes 2 and 14 also sustained moderate to heavy damage.

Structural damage was severe as several major bridges completely or partially collapsed while several others were damaged to the point of making them unsafe for public use. Other bridges received minor damage which did not affect their structural integrity. The number of bridges that either collapsed or sustained extremely heavy damage was small, however, when compared to the total number of structures in the affected area.

Road damage occurred in several forms including subsidence of fills, separated pavement slabs, buckled pavement, failures in cut slopes and fills, and settlement at bridge approaches. Although much of the damage was not as serious as it first appeared, major reconstruction will be required in some areas to restore the facilities.

Hospitals

The intensity of the earthquake was most manifest at the north end of the San Fernando Valley, north of the town of San Fernando. Two hospitals in this area sustained heavy damage resulting in high loss of life. Forty-four persons perished at Sylmar Veterans Administration Hospital when two 45 year old buildings collapsed. These structures had passed an engineering inspection only six months prior to the quake. Some 58 hours elapsed before the last survivor could be removed from the ruins.

At the Olive View Medical Center near Sylmar three died when the new 850 bed main building was very seriously damaged. Four stairwell wings were pulled away from the five story structure, three of which toppled over. Fortunately, at this location, the principal damage occurred within unoccupied areas.

Utilities

The earthquake inflicted great damage to utilities in the San Fernando area. The Sylmar Converter Station, southern terminus of the Pacific Northwest Intertie system, was particularly hard hit. Facilities of the General Telephone Company were damaged in the order of $4 million. Water conveyance and storage facilities of the Los Angeles Metropolitan Water District were heavily damaged and will require extensive and costly repairs. The main gas feeder line was severed under Glen Oaks Boulevard in San Fernando and the town lost its water supply as well. Potable water was scarce throughout the San Fernando Valley for several days as a result of disrupted or contaminated facilities.

A great threat to security of the population within the disaster area was posed by damage to the Lower Van Norman Lake Dam just west of San Fernando. This dam, which contains the largest water-storage reservoir in the Los Angeles Metropolitan area, successfully retained 3.6 billion gallons of water within the reservoir despite the fact that a major portion of its upstream slope and concrete facing had ruptured and slipped down into the water. Had the dam failed, a 100-foot high wall of water would have been loosed on the 50,000 inhabitants of the downstream area, confined within a natural channel two miles wide and seven miles long. The catastrophe was averted by reduction of the water level and sand-bagging. Some 80,000 inhabitants were evacuated from the danger area during the critical period February 9-13.

Private Homes

Some 4,000 structures suffered major damage in Los Angeles County itself. Los Angeles building and safety inspectors checked 11,772 structures in one week and found that over 2,000 had received major structural damage. Damage to buildings on private property within the city limits was expected to total $140 million. Private property damage as a result of the quake has been estimated to total $242 million by authorities.

Schools

Thirteen of 619 city schools suffered severe damage; ten of these were in the San Fernando Valley. The preponderance of the estimated damage occurred within the Los Angeles Unified School District where 35 schools suffered major structural damage and 28 schools incurred major non-structural damage. Repairs to schools in Los Angeles County were estimated at $23 million.

The results of the earthquake demonstrated the effectiveness of (measures required by) the Field Act of 1933. This law, which reflected public concern over structurally inadequate school building construction (revealed by the Long Beach Earthquake of 1933) required earthquake standards of design. It also gave the State Division of Architecture authority and responsibility for approving design and supervising construction of public schools. Schools built under Field Act codes performed well; older structures suffered greater damage.

Downtown Los Angeles

Los Angeles sky-scrapers "swayed like wheat stalks" during the temblor but none experienced damage worse than cracked plaster, broken glass or jammed elevators.

More than 200 seismographs or accelerometers were operating within the Los Angeles and Beverly Hills City limits at the time of the quake. Evaluation of data from these instruments should greatly advance knowledge of earthquake effects on structures.

CONCLUSIONS AND RECOMMENDATIONS

The work accomplished to date has resulted in the following conclusions and/or recommendations which are subject to modification pending further study.

(1) Overall cut slope performance was considered very good from the standpoint of slide development, although three slides did occur in very large cuts. One was a bedding plane failure and the remaining two (one of which had shown pre-quake sliding tendencies) developed in the upper portions of the slopes and did not collapse completely. The potential damage from large cut slope failures is very real, however, and large cuts should be evaluated for their failure potential in high earthquake risk areas. A fairly large bench near or slightly above mid-height of the slope to retain or slow potenial sliding masses and widening at-grade for storing slide material should both be given serious consideration where soils and geologic conditions are appropriate. Slope flattening in general would be beneficial and should be considered in conjunction with right-of-way restrictions, damage potential and other pertinent factors.

(2) Embankments were found to be susceptible to several types of damage including shear failure, subsidence due to densification, spreading, and longitudinal and transverse cracks caused by ground motion.

Damage to fills with respect to shear failure was considered minor despite the fact that three slipouts did develop in very good material. This suggests that high fills should be evaluated for their failure potential in high earthquake risk areas. Appropriate seismic coefficients should be used in design analyses for those sites where large fills over dynamically susceptible foundations are considered. Subsidence due to densification within the fill cannot be eliminated entirely and can be reduced only by keeping fill heights as low as practical. It is very doubtful whether increased compaction beyond that presently required would be economically desirable.

Although fill spreading was observed at some locations, it was very minimal. Further reduction of spreading could only be attained by providing slopes as flat as 4:1 or 5:1. This normally is impractical.

(3) Fill damage caused by foundation soil response to the earthquake consisted of (1) subsidence due to the more pronounced densification of looser underlying sands and gravel, and (2) slipouts initiated in the weaker, fine-grained soils supporting portions of Route 5 just north of the Route 5/405 Junction. No reasonable treatment outside the scope of current procedures is available for these problems. For example, the foundation failure on Route 5 resulted in a vertical subsidence of only one foot and even less lateral movement. The lack of greater movement indicates that the foundation material had good strength characteristics prior to the quake. Prevention or reduction of densification in loose foundation soils could be achieved only by costly predensification or by injection of material to fill the voids during construction.

(4) Another type of damage associated with fill subsidence is the differential movement at abrupt cut/fill contacts. This results in transverse cracks and vertical displacements across the pavement. For very shallow fills the problem was minor and no special treatment is recommended. For the higher fills the problem cannot be reduced without significantly flattening the slope contact between original ground and the new embankment. This would not be a practical solution. Emphasis should continue to be placed on requiring excavation to 6 feet into the existing hillside and recompacting the soil as now required when placing new fills.

(5) Settlement at bridge approaches is a complex problem that involves the bridge and its foundation as well as the embankment and its foundation, plus structural backfill material and the different dynamic responses of each element. The damage would be minimized if the dynamic response of the bridge, bridge foundation, embankment and foundation soils were all identical, but this is not technically feasible. Preliminary findings do indicate, however, that longer and stronger approach slabs would be of benefit. Structural backfill should consist primarily of sand with some silt being desirable to produce a well-graded material that will readily densify by presently used methods. Gravel, especially in large quantities, when mixed with uniformly graded sands hinders compaction by normal methods and results in a condition highly susceptible to much further densification by severe ground shocks.

(6) Because of the complex nature of California's geology - with its statewide system and subsystems of faults, it is sometimes necessary to construct a freeway across a fault that is either known or suspected to be active. Field observations indicate that road damage by post-construction fault movement can be minimized if the roadway profile across the fault is kept as close as possible to natural ground. The desirability of crossing a fault in cut or fill depends on the geologic, soils and geometric conditions at each site. Particular attention should be given to cut depth, especially in loose or badly fractured materials since falling boulders or slides represent potential hazards. Whenever fill sections are used they should be kept to a minimum.

(7) In the area damaged by the earthquake it is reasonable to assume that movement on the San Fernando Fault is not likely to recur within the next century.

(8) Strong ground motion, equivalent to that experienced in this earthquake, is quite likely to recur within the next 30 years. It is reasonable to assume that this ground motion will have a sizeable vertical as well as horizontal component.

(9) Rebuilding of freeway facilities at the sites damaged by this earthquake is reasonable provided seismic forces similar to that experienced during this earthquake are considered in redesigning the facilities.

(10) Geologic studies have been made on many highway projects. This process should be continued and expanded to include more projects with greater emphasis on seismic risk considerations. Particular attention should be placed on the location and geometrics of critical interchanges when they are planned near known active faults. This information should be available at the planning stage when there is some latitude in highway location.

(11) Consideration should be given to using variable seismic load factors in the design of structures and earthworks. Selection of the appropriate load factor should be based on evaluation of potential seismic intensity, estimated dynamic response of the foundation material, and the consequences of failure of the facility.

FIELD INVESTIGATION

INTRODUCTION

Investigation of earthquake damage to roads in the San Fernando Valley area was begun by the Materials and Research Department on February 19 and is still in progress. This work is being conducted to study damage to roadway earthworks, notably cut slopes and embankments. Although the project is oriented toward soils and geological aspects of the problem, other elements of the roadway are being reviewed for an overall appraisal of damage and for the sake of completeness. Because the study is primarily concerned with earthworks, it has been limited for the most part to highways. However, areas adjacent to but outside the highway rights of way are being studied so that much of the additional information so obtained can be related to different types of observed roadway damage.

Primary objectives of the project are to survey and record roadway damage, determine the mechanisms by which different types of damage occurred, and to determine if the damage is related to current design practices and/or construction methods. Work accomplished to date consists of a damage survey and extensive mapping of fault traces and ground breakage in conjunction with a review of regional geology. Work in progress includes subsurface exploration and sampling, engineering surveys to determine accurate relative movements of roadway elements, and more detailed geologic studies in some areas of special problems or complex geology.

STUDY AREA

The area being studied is shown in Figure 1 and consists of the northern portion of the San Fernando Valley and the Newhall-Solemint Junction area northeast of and separated from the San Fernando Valley by the San Gabriel Mountains. This is the area in which damage to freeways, private dwellings, and other structures was concentrated, although scattered damage (generally not involving roads) did occur in other areas of metropolitan Los Angeles.

The mapped area is shown in Figure 1. Detailed mapping is shown in Plate 1 and will be referred to later as the "map area." Practically all faulting and other ground breakage that affected major highways occurred in the map area.

Six major roads (five freeways and one State highway) traverse the earthquake affected area as shown in Figure 1. The most important single road is Interstate Route 5 (Golden State Freeway) which is the main north-south artery for traffic entering and leaving the northern metropolitan Los Angeles area. Interstate Route 405 (San Diego Freeway) junctions with Route 5 in the northern San Fernando Valley to provide a more direct north-south route through the metropolitan area westerly of downtown Los Angeles. About 2.2 miles north of the Route 5/405 junction, Route 5 interchanges with Interstate Route 210 (Foothill Freeway) at the southern base of the San Gabriel Mountains. Route 210 is a new freeway with only five miles having been completed in the general area. East of Maclay Avenue, where pavement ends, only fills have been constructed for another two miles. This route will be a perimeter facility beginning at Route 5 and skirting along the northern and eastern fringes of the metropolitan area paralleling and very close to the base of the San Gabriel Mountains. About 1.8 miles north of the Route 5/210 Interchange, the Sierra Highway (Old Route 14), an older four-lane road, junctions with Route 5 and extends easterly through Solemint Junction. At the Route 5/Sierra Highway Junction the new Route 14 (Antelope Valley Freeway) interchanges with Route 5 and also extends easterly, closely paralleling the Sierra Highway. From the interchange east to Solemint Junction the new Route 14 is under construction, in the earthwork and structures stage. The section of Route 5 between the Route 5/14 and Route 5/210 Interchanges is also under construction as new lanes (truck and auto) and connector roads are being added to ultimately provide a complex, high volume roadway system. To the south (two miles) of the Route 5/405 junction, the new Route 118 (Simi Valley Freeway) will interchange with both Routes 5 and 405. Route 118, a stage construction project with fills only having been constructed in the study area, is an east-west route extending from its eastern terminus, a planned interchange with Route 210 about one mile east of Maclay Avenue, to the west along the base of the Santa Susana Mountains into Simi Valley. This route will provide residents of the northwestern metropolitan area freeway access to the north-south freeways and hence the entire metropolitan area.

GEOLOGIC SETTING

General

The western San Gabriel Mountains show a history of complex faulting and folding that has occurred in the Cenozoic Era. The crystalline massif of the San Gabriels has been uplifting for the last several million years overriding the younger sedimentary strata along the south flank of the range along a series of north dipping discontinuous thrust faults. The series of discontinuous thrust faults comprise the Sierra Madre Fault Zone as described by Oakeshott (6).

The relatively weak sedimentary strata that flank the crystalline massif, form steep outcrops from the valley floor. The steep mountain front of the south side of the San Gabriels is an indication that the structural geology configuration of the San Fernando Valley area is very young in geologic time.

Topography

The map area under study is bounded on the north by the southerly base of the western end of the San Gabriel Mountains. Sedimentary rocks rise abruptly from the broad valley floor and are cut by deep canyons with steep walls that form a series of ridges oriented generally north-south and are nearly perpendicular to the strike of the steeply dipping bedded sediments.

The western boundary of the mapped area extends into the eastern end of the Santa Susana Mountains that are made up of sedimentary rocks that rise gently to moderately out of the valley floor.

The eastern end of the mapped area extends into sedimentary rocks of the San Gabriel Mountains where the valley is abruptly truncated by steeply rising stratified sediments.

The southern boundary of the mapped area extends across the San Fernando Valley from the southern base of the Santa Susana Mountains to the base of the San Gabriel Mountains on the east.

Alluvium

With a few exceptions, the alluvium that makes up the San Fernando Valley within the map area is made up of thick, loose gravel and sand with the source material derived mainly from the hard crystalline rocks of the San Gabriel Mountains that lie to the north. Alluvium in the valley floor in the vicinity of the Van Norman Lakes is composed of sand and silt with some gravel whose source area is probably the sedimentary rocks that lie to the north and to the west of the lakes. The alluvium in Grapevine Canyon was probably derived from crystalline rocks of the San Gabriels and sedimentary rocks from the northwest.

Tectonics

The tectonic history of the Cenozoic Era as determined from the decipherable record, (Oakeshott, 6, p. 89), "shows that intermittent, frequent, uplift of the San Gabriel mountain range took place, accelerated at times, with faulting, folding, and readjustment around the margins of that competent crystalline block (crystalline rocks of the San Gabriel Mountains)... a major zone of reverse faults separate the crystalline block from flanking Cenozoic stratified rocks along the south side of the range."

In and near the map area along the south side of the crystalline rocks of the San Gabriel Mountains Oakeshott, (6, pl. 1), has mapped a series of north dipping reverse faults that are within the Sierra Madre Fault zone. The Sierra Madre Fault zone as discussed by Oakeshott extends from the northeast end of the Santa Susana Fault (about 0.8 mile northwest of Route 5/210 Interchange) on the west to the Rowley Fault zone on the east, a distance of approximately 14 miles.

The Sylmar and Tujunga Faults shown on the map are the 1971 fault breaks that occurred at the time of the San Fernando earthquake. These faults lie within the Sierra Madre Fault zone.

The San Fernando earthquake and the resulting tectonic movements show that the activity of the Cenozoic Era described above is continuing today.

Geologic Significance of the San Fernando Earthquake

General

The 1971 fault breaks shown on the map and observed out of the map area by the writers indicate that regional deformation of the earth's crust occurred in the northern part of the San Fernando Valley and along the southern base of the San Gabriel Mountains. Regional, as used by the writers above is defined to include an area of several tens of square miles, but at this time the limits cannot be established.

In order to determine the limits and magnitude of deformation that has occurred, precise survey data will have to be analyzed when it becomes available.

Regional Uplift

The City of Los Angeles (4) measured a series of relative vertical changes in the Sylmar - San Fernando area based on the assumption that no change in elevation occurred at the intersection of Foothill and Van Nuys Boulevards. The vertical changes indicate that regional uplift, relative to the south, occurred on the north side of the Sylmar Fault zone that is shown on Plate 1. Table 1 is a summary of the vertical changes at various locations within the map area.

LOCATION	APPROXIMATE VERTICAL CHANGE (FT.)
Intersection of Route 210 freeway and Harding Avenue	+4
Intersection of San Fernando Road and queried Sylmar Fault	+1
Near Route 210 and Roxford Street interchange	+1.6
Near Route 210 and Foothill Boulevard intersection	+1.1
Route 5/210 Interchange and San Fernando Road	+2.6
Pacoima Dam (located about 1.3 miles northeast of the Veterans Hospital)	+1.1

Table 1

Faulting

Observations made along the Sylmar Fault and Tujunga Fault (Plate 1) show that they are reverse faults dipping north with the north thrust over the south. Where the extension of the Sylmar Fault crosses Routes 5, 405 (Plate 1), movement has occurred in an old fault zone that is well exposed in the road cuts.

The Sylmar Fault extension is vividly exposed where it crosses the Route 5 southbound truck lane and continues through the cut slope to the east as shown on Plate 1. Movement has occurred along bedding planes that dip about 60°N, with the north thrust over the south. The truck lane has been elevated about two feet on the north side along the fault trace.

The Tujunga Fault, where it is exposed in the bedrock east of the Foothill Nursing Home as shown on the map, dips from about 15° north to nearly vertical. The north block has been thrust over the south block. Six hundred feet west of Lopez Canyon Road (Figure 3) a fence that crosses the fault scarp at about a 45° angle has been shortened 2.7 feet along the fence line and the north side elevated about two feet. At this location the fault appears to parallel bedding planes that dip 30° north and strike east-west. The observed trace of the Tujunga Fault is nearly continuous to the east from the east map limit for a distance of approximately three miles along the base of the foothills. Fault breaks that occurred further east have been mapped by Kamb, et al (5).

The Sylmar Fault has a component of left lateral strike-slip movement that shows up vividly where the fault crosses Route 210, 550 feet west of Maclay Street. Figure 4 is a view of the fault at this location looking southeast, showing left lateral movement of approximately four feet. The faulting occurred in a zone approximately 400 feet wide where it crosses the freeway. Figure 5 is a view looking southeast across the fault where it crosses the Maclay Street westbound on-ramp, and shows uplift on the north block.

Ground breakage along the Sylmar Fault west of the freeway continues in a zone a few hundred feet wide to about 300 feet west of Glenoaks Boulevard as shown on the map. Figure 6 is a view looking west at the Sylmar Fault trace where it crosses the intersection of Adelphia Avenue and Harding Street.

Landslides

Several earthquake induced landslides occurred in the study area, with some affecting highways.

The Juvenile Hall slide shown on Plate 1 is of special interest because of its nature. The slide has occurred in alluvial

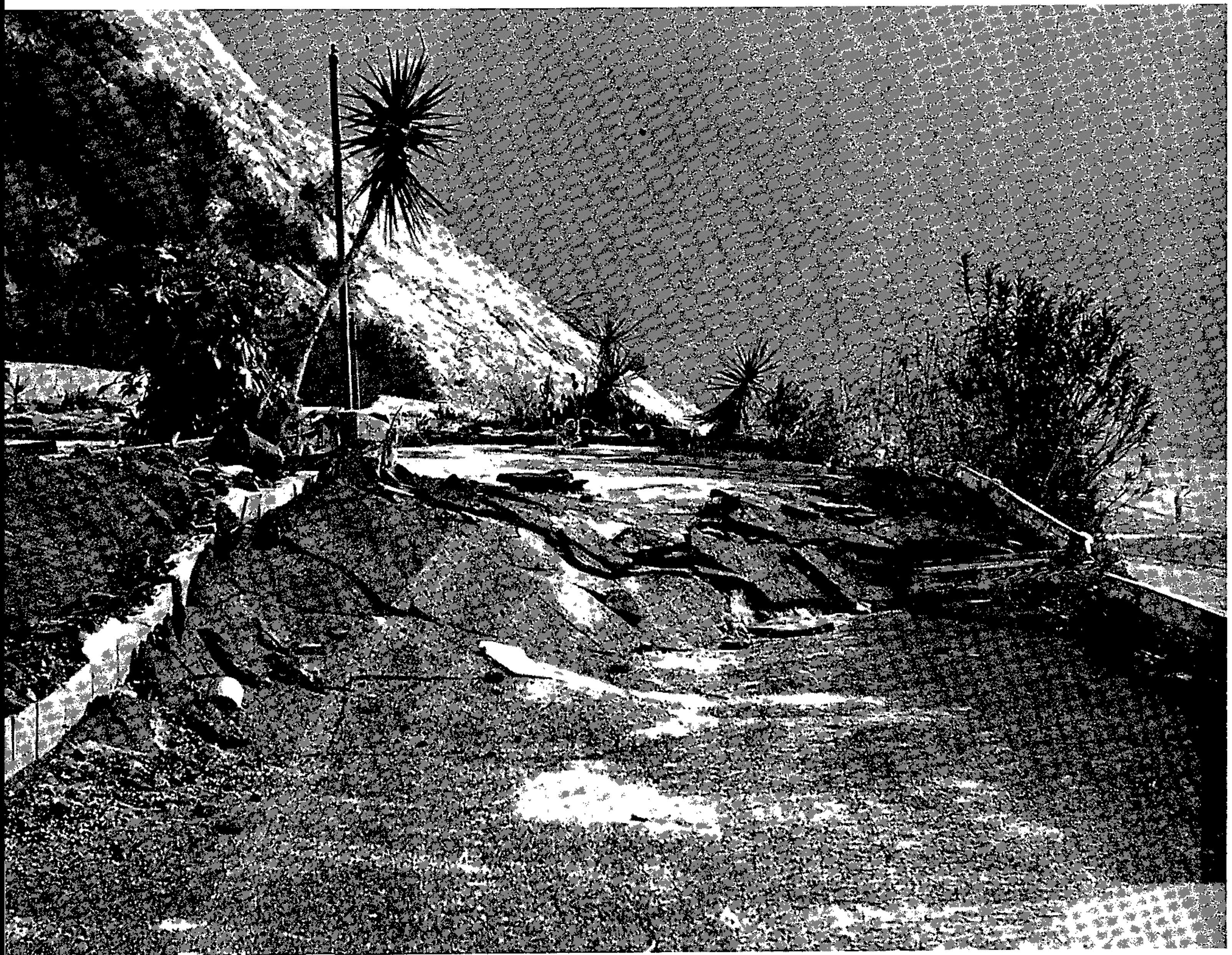


Figure 3 - Looking north at Tujunga Fault scarp 600 feet west of Lopez Canyon Road.

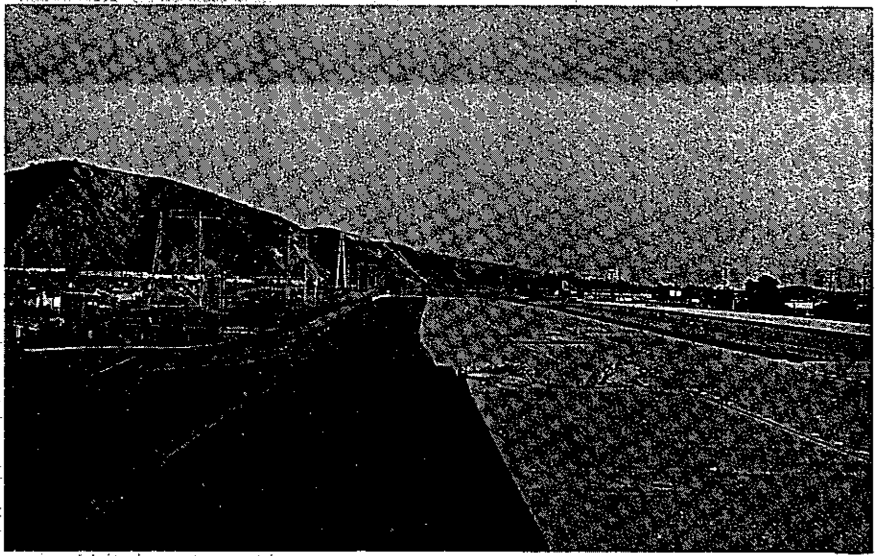


Figure 4 - Looking southeast at Sylmar Fault trace across Route 210.

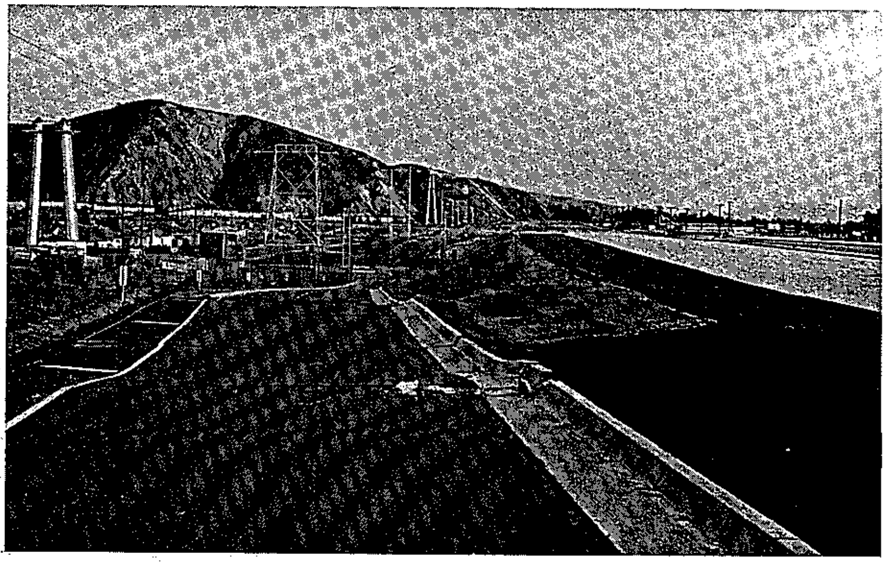


Figure 5 - Looking across the Sylmar Fault trace across Route 210/Maclay Street westbound on ramp.

Figure 6 - Looking west at the Sylmar Fault trace across the intersection of Adelphia Avenue and Harding Street.

Figure 7 - Looking north at concrete channel that shows displacement that occurred prior to earthquake.

deposits that have a very gently sloping surface with approximately 50 feet of relief from the Sylmar Converter Station to the head of the slide (slightly north of Juvenile Hall) in a distance of 3200 feet along the axis of the slide. A more complete description of the above slide and others follows in the section on ROAD DAMAGE.

Map Explanation

The main purpose of mapping has been to record ground breakage and stress patterns in an attempt to understand the regional effect of the earthquake and how this may relate to observed highway damage.

The numbers 1 through 12 circled on the map are explained as follows:

1. The penstock (near Route 5/210 Interchange) has an expansion joint at this location that expanded 12" at the time of the earthquake. The concrete footings that support the penstock show some displacement relative to the penstock on the west side and very little, if any, on the east side.

2. The concrete footings that support the penstock at this location have moved 14 inches south relative to the penstock. About 500 feet south of location 2, an expansion joint in the penstock expanded nine inches at the time of the earthquake. Immediately south of the expansion joint the footings have moved south about five inches relative to the penstock.

3. At this location it is reasonable to expect about two feet of relative horizontal displacement between the penstock and the concrete footings provided the penstock moved relative to the ground, based on observations in 1 and 2 above. No horizontal displacement was observed between the penstock and the concrete footings. From the above relations it appears that the ground and penstock moved together in a southward direction of about two feet.

4. A concrete electrical conduit (at the Sylmar Converter Station), buried, runs between manholes at locations 4 and 5. At location 4 the conduit broke at the manhole, was displaced about two inches southwest, and moved downward a few inches relative to the manhole.

5. At this location the buried conduit moved downward eight inches relative to the manhole (oral communication with repairmen). No horizontal displacement relative to the manhole was observed by the repairmen.

Movement within locations 4 and 5 may be an extension of the Juvenile Hall Slide.

6. The PCC roadway pavement (Route 405) within a cut section is bulged at this location for a distance of about 100 feet, with about 1/2 foot of relief. The bulged section overlies silt and mudstone beds that dip nearly vertical and strike approximately east-west (transverse to the roadway). As exposed in the cut face, the silt and mudstone beds are bounded on the north and south by sandstone. This location is about 600 feet south of a fault break. Possibly compression was absorbed in the silt and mudstones, which expressed itself at the surface as a bulge.

7. Old patched pavement cracks at this location (Route 5, north map boundary) were opened up and extended in a zone 600 feet long that extends to the south of the number where it appears on the map.

8. Within the Olive View Hospital facility at this location, an old concrete channel shows displacement that probably occurred over a period of years prior to the earthquake. Figure 7 is a view of the channel looking north. East of the channel, ground breakage occurred at the time of the earthquake. On the map, an eastward extension of possible faulting is inferred where queried.

9. At this location severe slope shattering has occurred in a long, narrow zone east of the Olive View Hospital with an east-west trend as shown on the map by a dashed line. The queried extension of the zone to the east has not been examined by the writers. Houses in the tract south of the zone suffered severe structural damage. The most severely damaged houses have been blocked out on the map.

10. Near the southeast corner of the map area at this location, ground breakage occurred in a trailer manufacturing plant. On the north side of the building site a one-foot scarp was formed, south side up, as shown on the map (oral communication with plant employees). Shortly after the earthquake the area was graded and an oil-pea gravel covering was placed. At the time the site was studied by the writers, fresh cracks were in the oil-pea gravel cover. Some of the post-earthquake breakage occurred along bedding planes in weak shales.

The hills to the east of the manufacturing plant are severely broken up in a complex manner as shown on the map. From the manufacturing plant south to the Tujunga Fault and southwest to the Foothill Nursing Home, numerous ground breaks have occurred in addition to those mapped.

The hills north of the Foothill Nursing Home as described above have been weakened over a large area due to the earthquake. A proposed interchange of Routes 210 and 118 is presently planned to use a part of the hills north of the nursing home.

11. This location in the southeast corner of the map, bounded on the east by the base of the hills and extending northwest at least to Arroyo Drive is in a zone of compression. Industrial buildings within this area suffered heavy damage from compression ridges formed in the alluvium and from ground breaks.

12. The Route 5/210 Interchange at this location suffered many undulations and pavement slab separations along expansion joints in the pavement. Intense slope shattering of the hills to the northeast indicates that a large amount of energy was released in the Interchange area.

ROAD DAMAGE

General

Major road damage, and certainly the more spectacular, is concentrated within an area of about 12 square miles and involves only 10 miles of freeway. The fact that road damage within this small area is much more severe than damage outside the area is attributed to the large concentration of energy released during tectonic movements. All principal elements of the roadway sustained damage as direct results of seismic shaking, much stronger than would have been expected for a 6.6 magnitude earthquake. Damage was reflected in the following forms:

1. Cut slope failures

2. Subsidence of fills and underlying materials

3. Shear failures in fills and foundations

4. Faulting, separation, and buckling of pavement slabs

5. Cracking, separation, and distortion of drainage structures

6. Collapse and serious structural damage to bridges

7. Settlement at bridge approaches

Cut Slopes

Several slides in cut slopes were caused by the quake. The larger slides occurred on construction projects but would have had minimal effect on the travelled way had the road been in service. One exception, shown in Figure 8, was a bedding plane failure left of Station 1640 on Route 5. This slide would have blocked Ramp "V" which is designed to connect southbound traffic from Route 14 with San Fernando Road. Moderate to large earth volumes were involved in the three larger slides. Smaller slides were much less spectacular and some involved movement so small

Figure 8 - Cut slope bedding plane failure left of Station 1640, Route 5.

they were not detected during an initial damage survey. These slides, however, have affected the travelled way by their upthrusting action on the pavement section causing diagonal and longitudinal cracks and portions of the pavement to raise noticeably.

The behavior of cut slopes was dependent on type of material. For example slopes in dense, stiff, brittle materials (silts and silty sands containing enough non-plastic fines to have undergone desiccation to the extent that a cemented appearance was evident) fractured and shattered badly over distances of 20 to 30 feet behind top of cut, and often in the face itself. Materials of moderate density and a slightly greater moisture content experienced far fewer cracks and no shattering. Often only one or two large cracks were found along the slope top. Slopes in loose materials cracked behind the slope (where surface desiccation had occurred) in a parallel pattern and the slope moved successively in small amounts at each crack toward the unsupported surface. Sloughing or slumping in the slope face also occurred in this type of material.

Embankments

The type of damage most often observed was subsidence due to vibratory densification of fill and foundation materials, both of which consist of non-plastic silty, gravelly sands except at isolated locations. Subsurface soils were densified not only under fills but in areas outside the confining influence of fill weight. Greater densification did occur under the fills, however, especially at locations where the materials were in a very loose state prior to the quake. Generally, densification of foundation materials resulted in much greater amounts of fill subsidence than densification of the fill itself because the deposits of alluvium affected by the ground vibrations were in a looser pre-quake condition than the fill and are substantially deeper at most locations than fill thickness.

The contribution of subsurface soil densification to fill subsidence can easily be detected at locations where rigid inclusions in natural ground pass under the fills. Differential subsidence results from ground shaking and a ridge or high area in the roadway surface is created over the non-yielding inclusion. As the fill on either side of the rigid element subsides, shear cracks are formed in the fill slopes, beginning at the toes and extending up the slope face. In cases of small relative movement the cracks may extend only about half way up the slope, but as total subsidence increases the cracks continue to develop and extend across the roadway. They may or may not be reflected in the pavement section but can be observed in unpaved medians and shoulders. This type of differential subsidence occurred at the Polk Street/210 interchange and on Route 5 just north of Rinaldi Street. At both locations, a reinforced concrete box drainage channel was crossed by fills about 25 feet in height.

Some spreading of fills near structures is associated with densification within the fill due to the tendency for movement toward unsupported surfaces. This type of spreading in the fill proper was minimal, fairly uniform, and confined for the most part to the ends of approach fills under bridges. Fill spreading caused by lateral movement in foundation soils during densification was observed at a few locations but was limited in amount due to the inherent high shear strength of foundation soils. This resulted in bulging in the lower half of fill slopes and formation of longitudinal tension cracks in the upper half as the fill subsided differentially in a plane normal to centerline. Enough lateral movement near the fill toe did occur at some locations to cause minor thrusting of inside curb and gutter sections of freeway ramps. Also, as the fills subsided, the lateral component of slope paving movement sheared and rotated the curbs along the surface streets under the freeway structures.

Slipouts varying in size and amount of movement occurred in fills at several locations. Maximum movement did not exceed what normally would be considered a small amount but was sufficient to cause differential vertical displacements at longitudinal joints in pavement slabs, diagonal cracks across the pavement at the flanks, and minimal thrusting near the toe. Larger movements were prevented by the high strength properties of fill and foundation materials. The larger slipouts experienced the greatest movement and were observed to have occurred in long fills, all of which were 20-30 feet high. The smaller slipouts often experienced very little movement and in some cases were difficult to detect. They usually occurred in fills crossing small ravines and developed because of differential response by fill and natural ground. Consequently, lateral limits of these slides generally followed the cut/fill contact.

Three fill slipouts caused by plastic type movements in fine-grained compressible foundation soils occurred within one fairly small area on Route 5 just east of the Lower Van Norman Lake. These slipouts involved more vertical and lateral movement than those occurring in fills only. The portion of fill undergoing movement dropped a maximum of one to 1.5 feet. Lateral movement was somewhat less due to the rotational effect, but large cracks up the fill slope were formed at the flanks. These slipouts covered a larger portion of the roadway than those in fills only.

The effect of subsidence and associated cracking on fill stability is considered negligible because of the high quality of fill materials. However, large quantitites of water entering the larger cracks may cause sliding and sloughing within slopes and shoulder areas. Slipouts within fills only do not present stability problems for the same reason. No additional slippage is expected at locations involving failure in foundation materials since no additional loading is anticipated and the soil strength will be improved to near pre-quake levels through consolidation.

The overall effect of fill subsidence is a loss in roadway profile at cut/fill contacts and bridges. In some cases, especially at bridges, this abrupt change in profile is large enough to prevent traffic use of the road. In other cases the bump at bridge approaches is accentuated but traffic can still use the facility. Reconstruction will therefore be concerned largely with adjustment of profile.

Juvenile Hall Slide

One large translational slide in natural ground was located and mapped in the general area of the Route 5/210 Interchange area. This slide, covering about 60 acres of relatively flat ground, wrecked the San Fernando Valley Juvenile Hall just east of the Interchange, and displaced a 1000-foot section of Route 5 about 5 feet to the west. A concrete lined channel parallel to Route 5, between the roadway and the Sylmar Power Converter Station, absorbed the slide movement but was demolished. Near the middle of the slide mass several sand boils were discovered which, although of small to moderate size, indicates liquefaction occurred in at least a portion of the slide.

Field evidence indicates the slide continued to move at a slow but decreasing rate during the first few days after the quake and then ceased moving. Recent aftershocks have had no measurable effect on the slide mass and no additional movement of any consequence is expected. However, the slide is currently being studied in detail and three boreholes along its axis have been made to obtain undisturbed soil samples.

The Pavement Section

Damage to the pavement section was found to depend almost entirely on the response of underlying materials to the ground motion and shocks generated by the quake. The most prevalent types of damage consisted of lateral and longitudinal separation between slabs at joints, differential vertical movement and resulting loss of pavement plane, transverse and diagonal cracking, and buckling at compression zones.

Separation between slabs with no detectable loss of constructed roadway plane was usually small and resulted from the response of fills to ground shaking. In some cases the slabs separated by moving over the cement treated base which remained uncracked, while in other cases the entire depth of section moved due to crack development in the CTB. Separation without crack development in the CTB probably resulted from ground shocks sufficiently large to break the bond between slab and base. The noted occurrence of this type of separation was infrequent since in most instances slab separation resulted from another type of damage or response.

Slab separation was generally accompanied by differential vertical movements over areas of various sizes. Actual relative vertical and horizontal movements between any two adjacent slabs were often quite small, and at some locations even difficult to observe except from certain vantage points. Nevertheless, the paving plane was disrupted and could be felt when driving over the affected slabs at freeway speeds. These differential vertical movements occurred mostly in fill sections where the underlying fill material had subsided and created a dip, but some were noted in cut sections where the slabs had been raised due to an upthrusting action at the toe of potential slides involving the cut slope.

Slab separation accompanied by differential vertical displacements along longitudinal joints was noted at a few locations in fill sections. These were locations of well delineated slipouts within the fill. If enough movement had occurred within the slipout delineation, diagonal cracks across slabs were in evidence.

Slab cracking at locations other than joints resulted from relative movement along the contact between cut and fill. In some cases where original ground was very steep, movement was practically vertical and no differential horizontal movement along the crack was noted. Separation along joints was noted in some cases but was apparently absent at others. Diagonal cracks not associated with slipout delineations resulted from differential lateral movement of underlying materials such as the San Fernando Juvenile Hall Slide. This type of cracking was generally accompanied by rotational type slab separation at joints on either side of the diagonal shear crack.

Slab separation in the vicinity of separation structures is believed to have been partially caused by the action of the structure being transmitted through the approach slabs to the pavement slabs, especially near those structures that experienced the more violent motions.

The remaining type of damage to the pavement section consists of compression buckles. This phenomenon was observed to occur almost exclusively in at grade sections, the one exception being in cut along the line of contact between bedded sediments and alluvium. This type of damage is believed to result from compressional shortening within natural ground.

Faulting due to tectonic activity previously described resulted in slight to moderate observed road damage. The well-defined Sylmar Fault, for example, crossed Routes 210, 5, and 405 almost normal to roadways at locations sufficiently removed from separation structures that no damage to bridges resulted. The fault crossed Routes 5 and 405 immediately south of their junction (just east of the Lower Van Norman Lake Dam) where both roadways are in cut and resulted in very minor breakage in the pavement section. The thrusting effect, however, did disrupt the pavement profile as the north side of the fault break moved up relative to the south side. The break in roadway profile was not serious and was feathered in fairly easily with AC patching. The fault crossed Route 210 about 550 feet west of the Maclay Avenue undercrossing at a location where the roadway was almost at grade. Upthrusting of the west side was more pronounced than at the Routes 5 and 405 fault trace, and a much wider zone was affected as shown in transverse cracks in pavement slabs and separation and vertical displacements of slabs at joints. Damage was more severe than at the Routes 5 and 405 fault trace due to the greater relative vertical movement at the main fault trace and the longer lengths of pavement within the fault zone. Damage at this fault crossing was considered moderate.

The possibility of other damage from more subtle manifestations of fault activity is still being investigated.

Drainage Structures

The drainage structure survey of this particular investigation is still being conducted and results to date are of a cursory nature only.

Damage to drainage structures was largely dependent on the response of earthworks in and under which they were constructed. Reinforced concrete boxes and pipes sustained cracks and joint separations ranging in size from hairline to one or more inches, exposing reinforcing steel in many cases. Corrugated metal pipes are frequently distorted in shape but generally are strucally intact. A frequent but fairly minor damage observed was cracking in concrete headwalls.

One of the most serious problems involving damage to drainage structures is differential movement which affected invert profiles. At most locations of pipes under fills, the sags in profiles resulted due to foundation subsidence. At other locations, however, it appears that flow directions may have been reversed.

Bridges

Damage to separation structures can be divided into three types according to severity as follows:

1. Collapse (total or partial)

    a. from ground motion

    b. by structures falling from above

2. Non-collapse

   a. severe structural damage

   b. minor structural damage, moderate to severe superficial damage

   c. little or no structural damage, minor superficial damage

3. Negligible overall to no damage.

This classification serves only as a convenient aid in describing in general terms the damage to bridges and is not intended as a complete, definitive system.

The Route 5 (truck lane)/405 separation collapsed as shown in Figure 9, and two spans of the South Connector Overcrossing at the Route 5/14 Interchange collapsed. At the Route 5/210 Interchange the San Fernando Road Overhead was so badly damaged it was on the verge of collapse and was removed almost immediately. Also at the Route 5/210 interchange, the Route 210/5 separation and overhead, a long curving structure, collapsed as shown in Figure 10, falling on the eastermost span of the northwest connector overcrossing and the northernmost span of the San Fernando Road overhead (widen) in the process. Thus two structures had spans knocked down by another structure falling from above. Other spans of the San Fernando Road overhead collapsed from ground motions, however, and the structure was judged a total loss requiring removal. The northwest connector overcrossing suffered the same fate.

A total of five structures will require complete replacement, two spans at the Route 5/14 Interchange will require replacement, and either extensive repair or partial removal and replacement of a portion of the Los Angeles Aqueduct Channel Extension structure will be required.

Other types of major structural damage consist mainly of shearing and spalling of columns by compressive forces, translation and rotation horizontally, and loss of deck profile accompanied by deck crack formation due to differential movement of abutment supports.

The majority of lesser damage, especially that not directly associated with structural integrity of the bridges, was caused by relative movement between elements of the structures. Damage is reflected in separation of wing walls from abutments, shear cracks through abutments, and spalling at joints and other locations of compressive force concentrations.

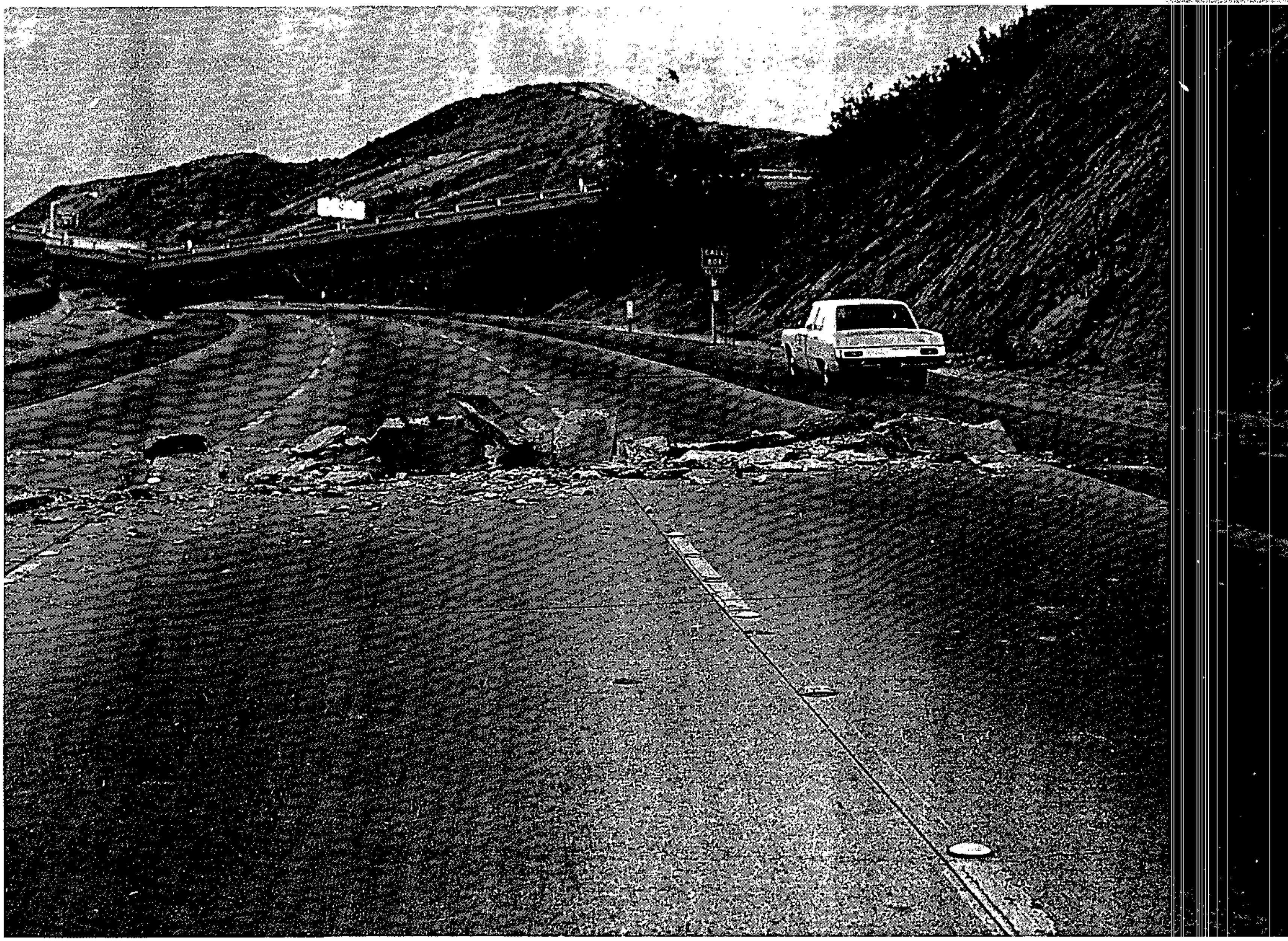


Figure 9 - Collapsed Route 5 (Truck Lane)/405 separation structure and buckling in pavement.

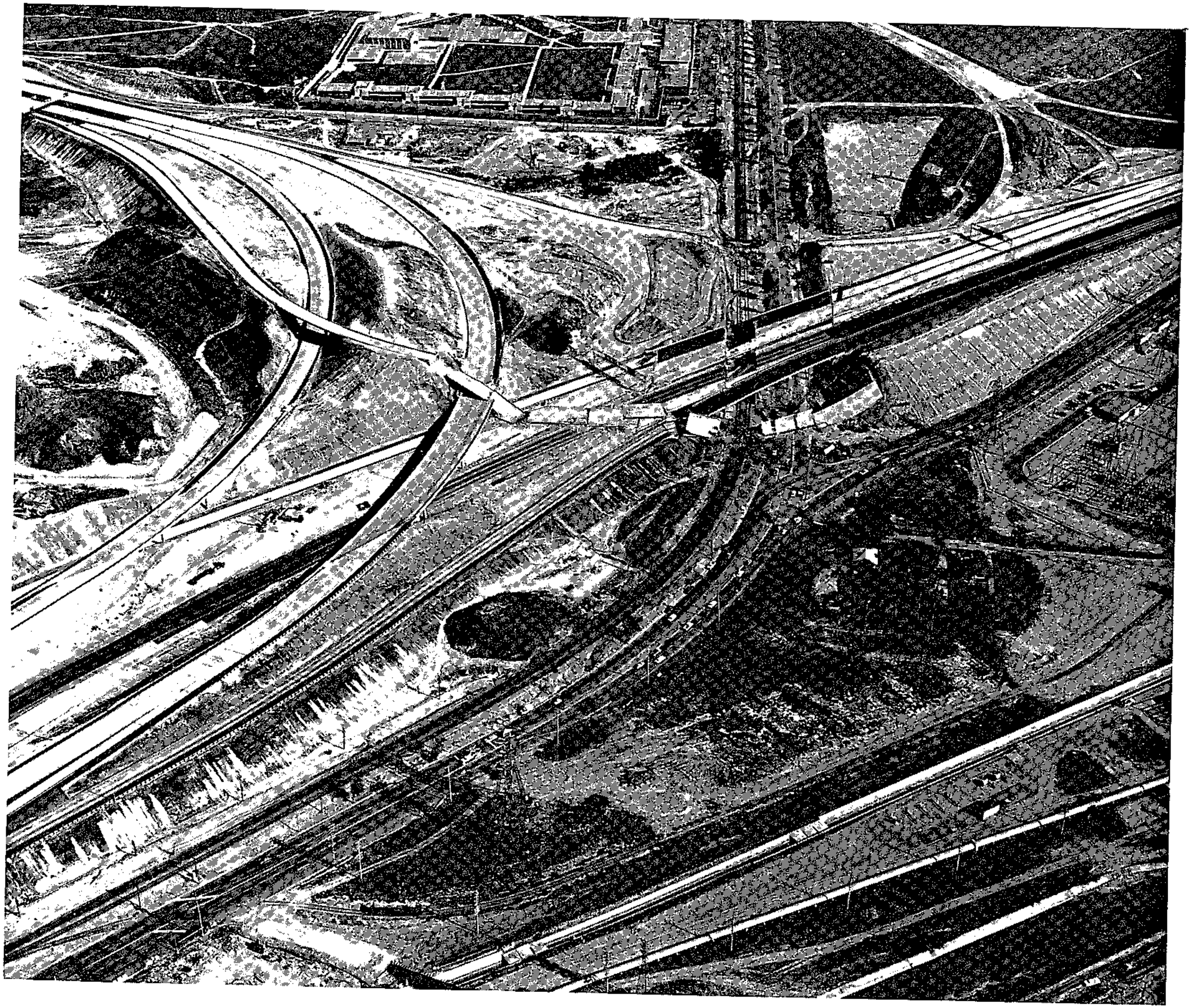


Figure 10 - Aerial view of Route 5/210 Interchange showing damaged structures.

A portion of one of the structures that failed at the Route 5/210 Interchange was constructed with steel girders. All the other freeway structures in the immediate vicinity were of concrete construction. Two other steel structures on the freeway system (Pico-Lyons Overcrossing and Valencia Boulevard Overcrossing) suffered only minor damage but are somewhat removed from the area of large energy release. However, a steel railroad structure is located in the vicinity of the Route 5/210 Interchange just north of the Sylmar Power Converter Station and immediately west of San Fernando Road. The overall effect of the quake on this structure is remarkably similar to that on the Pico-Lyons Overcrossing. The bridge is part of a spur line under construction to serve the Metropolitan Water District's Balboa Water Treatment Plant, also under construction just north of the upper Van Norman Lake. The bridge spans the Los Angeles Aqueduct and the 8-foot penstock that feeds the San Fernando Power Plant, and consists of six spans, each simply supported, of double wide flange steel beams. Abutments are of the old (especially rural) highway type, consisting of a backwall and flared wings (cantilevered) with bearing probably being attained with piles. Timbers had been placed across the beams but tracks had not been laid over the structure or on approach fills. Design of the structure is simple and effective for its intended purpose. Visible reaction of the bridge to the quake consisted of a slight (1/8"-1/4") inward movement of both abutments as shown by bearing assemblies, perhaps one inch of approach fill subsidence, and a hairline crack in the north wingwall of the east abutment. It is difficult to assess the severity of ground motion and shocks in the very immediate area of the structure, but very large ground breakage and movements occurred a few hundred feet to the west.

Bridge Approaches

Widespread settlement at bridge approaches occurred on all freeways surveyed for damage. This problem varies according to distance from the heavily damaged area and stage of construction of the road. For example, on existing Routes 5 and 405 south of the Mission Hills, the problem clearly affected the rideability, especially on Route 405, even after hasty AC patches were placed at approaches to relieve the abruptness of changes in profile. Very important, however, is the fact that the settlement was not so great as to prevent traffic use of the facilities without further repair work. The effect was much worse on Route 210, which was closed to traffic for an indefinite period, as differences in roadway profile in excess of one foot were noted at some bridge approaches. This means that restoration of profile will require pavement removal for some distance on both ends of structures to raise profiles and then repaving. On construction projects not yet paved, Routes 14 and 5, the problem can be corrected fairly easily since no pavement removal is involved.

Settlement at approaches is the result of subsidence of embankments and structural backfill material. Although the backfill material subsides more due to densification than the fill itself, it is usually the fill and not the structural backfill that is the principal cause of the problem. This is because of the bridging action of the reinforced concrete approach slab which is supported at the bridge deck by the paving notch and at its other end by fill material. The slab, therefore, is a transition between profiles of the bridge deck and the fill and acts as a ramp up to and down from the bridge deck. The fact that the slab is unsupported by the structural backfill becomes important only if the slab (1) falls off the paving notch, (2) fails by cracking along or near the fill/backfill contact, or (3) is of insufficient length to provide adequate bearing area on the fill. If any of the three conditions exist or occur the situation is worsened and it first appears that the structural backfill only is entirely responsible for the problem instead of merely contributing to it.

Field investigations of settlement at approaches are continuing and should provide further clarification of the problem as created by the earthquake.

DISCUSSION OF SEISMIC RISK OF THE SAN FERNANDO VALLEY

General

Prior to the San Fernando earthquake a certain amount of geologic information was available on the San Fernando area. For example, the California Division of Mines and Geology Bulletin 172 (6) covered the area. Masters' theses were also available that were pertinent to the area. This literature indicated that large offsets had occurred along faults in the area in Post Pliocene Time. However, none of these reports pointed out any historically recent ground breakage.

The exploration done by District 07 for the Route 5/Route 210 Interchange disclosed the large number of faults in the area, however, this work did not indicate any historic record of ground breakage. In fact, engineering geologists that worked within the Los Angeles area did not consider this site to be any more likely for ground breakage than other sites within the Los Angeles Basin.

Intensive investigation in the area following the quake did reveal that there was some indication of recent ground offset, however, normal investigations for engineering works probably would not have revealed this information.

EVALUATION OF PRESENT SEISMIC RISK

In order to evaluate the present seismic risk of the damage area, two aspects must be considered - ground breakage and shaking.

Fault Movement

In evaluating the potential for rupture along a fault, historical records are often used. The faults that broke during this earthquake had no historical record of prior breakage for at least the past 100 years. It is true that geologic studies indicate considerable movement in a fairly short geologic time. It is probably reasonable to assume that the faults that broke in the San Fernando earthquake will not break again for another 100, possibly 200 years. It is possible that those faults have a sporadic pattern of breakage. It is also possible that adjustments could occur on these faults because of an earthquake on another fault system such as the San Andreas. A creep phenomena may be associated with the fault movement from the San Fernando quake. This suggests that if construction is scheduled in the Route 118/210 area within the next year a monitoring program should be set up to determine whether creep is taking place.

Ground Motion

The Richter magnitude of 6.6 for the San Fernando earthquake is considered to be a moderate earthquake. However, ground motion in a localized area was quite severe. Strong motion accelerometers at Pacoima Dam showed ground motions both vertically and horizontally that were 50 to 75 percent of the earth's natural gravitational acceleration that lasted approximately 12 seconds. As was indicated in the consideration of potential ground breakage, an earthquake originating near the epicenter of the San Fernando quake is not anticipated for another 100 or 200 years, however, earthquakes of magnitude 6 or greater occur about one per year in Southern California. These quakes would probably not produce the intense ground motion in the San Fernando area although intense ground motion might occur within the Los Angeles area. A great earthquake (magnitude 8 or greater) is likely to occur along the San Andreas Fault somewhere between Tejon Pass and San Bernardino between now and the end of the century. This great quake could readily generate ground motion in the San Fernando Valley that would be as severe as the ground motion from this local earthquake. In fact, the duration would probably be longer. The large vertical component of the ground motion has come as a surprise to many people, however, other earthquakes with a vertical component have occurred in California. For example, the earthquakes that occurred in Kern County in 1952 had a vertical component. It is also reasonable to expect that movement occurring along the San Andreas Fault between Tejon Pass and San Bernardino would generate a sizeable vertical component.

It seems reasonable to assume that structures located within the San Fernando Valley will be subject to ground motion, quite possibly ground motion as severe as that which occurred from the San Fernando earthquake within the design life of the highway. It is also reasonable to assume that there will be a considerable vertical component to this ground motion.

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